[*Reprinted from* SCIENCE, *N. S., Vol. XLI., No. 1061, Pages 625–632, April 30, 1915*]

STANDARDS OF VENTILATION IN THE LIGHT OF RECENT RESEARCH[1]

THE fact that the stagnant air of an occupied room becomes uncomfortable and makes those who are exposed to it listless and inert is a matter of common experience. When overcrowding in a close unventilated space reaches a certain point the results may even be fatal within a few hours, as in the Black Hole of Calcutta, the underground prison at Austerlitz and the hold of the ship Londonderry. Conversely the value of fresh air in the treatment of tuberculosis and other diseases is one of the fundamentals of medical and hygienic practise.

For the sanitarian it is necessary, however, to know something more than this general fact that bad air is bad. He must not only have some workable conception as to its operation, but also a more or less definite standard of permissible deviation from absolute purity.

In the earlier days of ventilation this was an easy task. It was natural to assume that the evil effects of the air of occupied rooms was due, either to lack of oxygen or excess of carbon dioxide, or to the presence of some specific organic poison of human origin—morbific matter or anthropotoxin, as this hypothetical substance was called. Of either of these changes the amount of carbon dioxide should serve as a fair measure, and a carbon dioxide standard was therefore confidently advanced by the older sanitarians as a practically all-sufficient measure of atmospheric vitiation. Even as late as 1910 in the excellent textbook of Hoffman and Raber one could read that carbon dioxide

> is constantly being diffused throughout the air of the room, thus rendering it unfit for use. If this carbonic acid gas could be dissociated from the rest of the air and expelled from the room without taking large quantities of otherwise pure air with it, the problem of the heating engineer would be simplified, but this can not be done.

Yet Pettenkofer as long ago as 1863 showed clearly that carbon dioxide in itself is quite without effect in the highest concentrations which it ever attains in occupied rooms, and during the last fifteen years the researches of Flügge, Haldane, Hill, Benedict and other physiologists have rendered the older and more naïve view of the subject entirely untenable. Their studies indicate beyond any reasonable doubt that the more obvious effects experienced in a badly ventilated room are due to the heat and moisture produced by the bodies of the occupants, rather than to the carbon dioxide or other substances given off in their breath. Two fundamental experiments have been repeated again and again by these observers which alone would suffice to demonstrate, as Professor F. S. Lee has so well expressed it, that the problem of ventilation is not chemical, but physical—not respiratory, but cutaneous. These are, first, that subjects immured in close chambers, and exposed to the heat as well as the chemical products formed therein, are not at all relieved by breathing pure outdoor air through a tube; and, second, that they are completely relieved by keeping the

[1] Paper presented at a Symposium on Ventilation at the Philadelphia meeting.

chamber artificially cool without changing the air at all, and are relieved to a considerable extent by the mere cooling effect of an electric fan.

When the New York State Commission on Ventilation began its work last year it seemed that in spite of the establishment of these broad principles the subject deserved further detailed study at its hands, particularly in regard to possible undetected effects of chemical impurities and in regard to the harmful influence of moderately but not excessively high temperatures which have received but little attention in earlier researches.

The work of the N. Y. State Commission was made possible by a generous gift of Mrs. Elizabeth Milbank Anderson through the N. Y. Association for Improving the Condition of the Poor, and the members of the commission are Mr. D. D. Kimball, Professor F. S. Lee, Dr. J. A. Miller, Professor E. B. Phelps, Professor E. L. Thorndike and the writer. The experiments so far conducted have been carried out in two experimental rooms placed at our disposal by the trustees of the College of the City of New York and now equipped so that the atmospheric conditions in one room can be very closely controlled by apparatus located in the other. In the observation room over one hundred different subjects in groups of four have been exposed for periods of from three and a half to eight hours a day for from one to eight weeks in each series of experiments, to known conditions of temperature and humidity and atmospheric vitiation and their physiological and psychological reactions and mental and physical efficiency observed and measured by the most exhaustive methods.

The results of our experiments to date have been presented before the American Public Health Association at its Jacksonville meeting and may be briefly summarized as follows:

Even quite extreme conditions of heat and humidity (86° with 80 per cent. relative humidity) had no measurable effect upon the rate of respiration; dead space in the lungs; acidosis of the blood; respira-

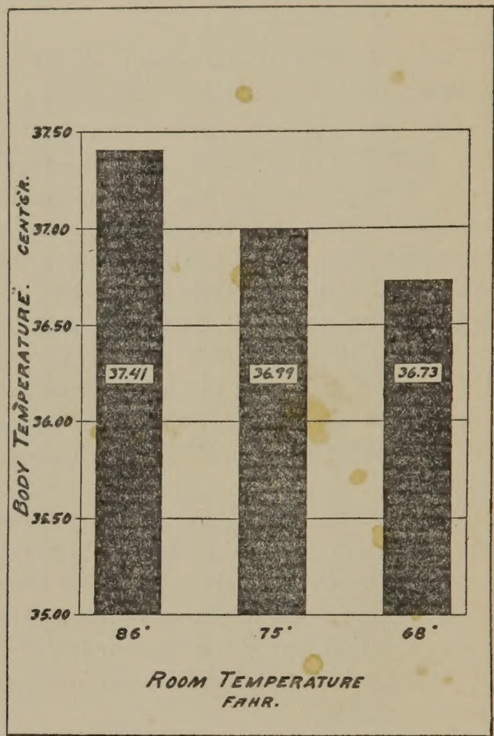

FIG. 1. Relation between Room Temperature and Average Rectal Temperature of all subjects at end of day.

tory quotient; rate of digestion and rate of heat production (both measured by oxygen consumption); protein metabolism (measured by determinations of creatinine in the urine); or skin sensitivity.

On the other hand, the working of the circulatory and heat regulating machinery of the body was markedly influenced by even a slight increase in room temperature, as, for example, from 68° to 75° with 50 per cent. relative humidity in both cases. In a hot room (86°—80 per cent. relative humidity) the rectal body temperature usu-

ally rose during the period of observation; in a warm room (75°—50 per cent. relative humidity) it remained on the whole about constant; in a cool room (68°—50 per cent. relative humidity) it fell. The average body temperatures attained under these three room conditions were 37.41°, 36.99° and 36.73°, respectively. So the reclining heart rate rose in the hot room to a final

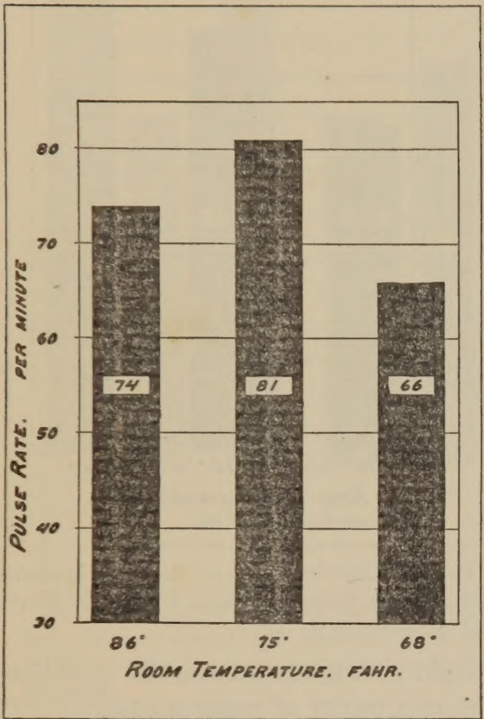

FIG. 2. Relation between Room Temperature and Average Reclining Pulse Rate of all subjects at end of day. (High value at 75° due to preceding physical work not duplicated at other temperatures.)

average of 74 beats per minute and fell in the cool room to a final average of 66 beats (the warm condition not being comparable in this case). I use the terms hot, warm and cool throughout for the three temperatures and humidity combinations cited above. The increase of heart rate on passing from a reclining to a standing position became greater (by an average of 7 beats) during a sojourn in the hot room; while it became less by an average of 3 beats in the warm room and by an average of 7 beats in the cool room. The systolic blood pressure was slightly decreased in the hot room (112 mm. against 116) and the Crampton value was markedly de-

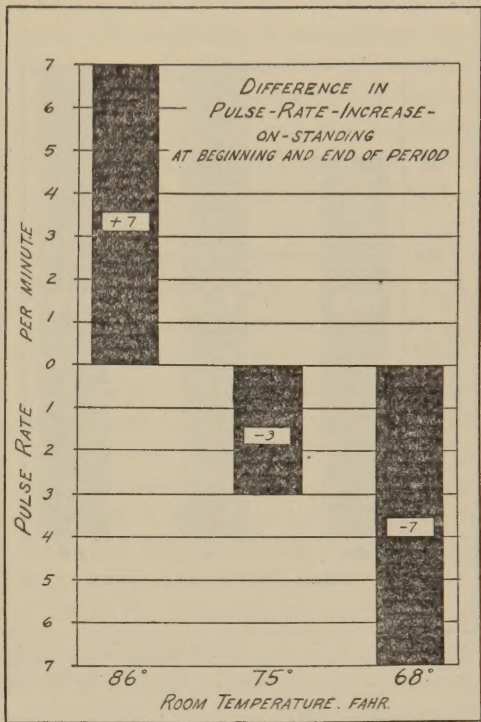

FIG. 3. Relation between Room Temperature and Average Difference between Increase-in-Pulse-Rate-on-Standing after reclining at end of period and similar increase at beginning of period.

creased, averaging 35 for the hot room, 45 for the warm room and 60 for the cool room.

Elaborate psychological tests of color naming, naming opposites, addition, cancellation, mental multiplication, typewriting and grading specimens of handwriting, rhymed couplets and prose compositions, all failed entirely to show any effect of even the severe 86°—80 per cent. relative humidity condition upon the power to do mental work under the pressure of a maximal efficiency test. Option tests of the inclina-

tion to do work, in which the subjects had the choice of doing mental multiplication or typewriting for pay, or of reading novels or doing nothing, showed a distinct lessening

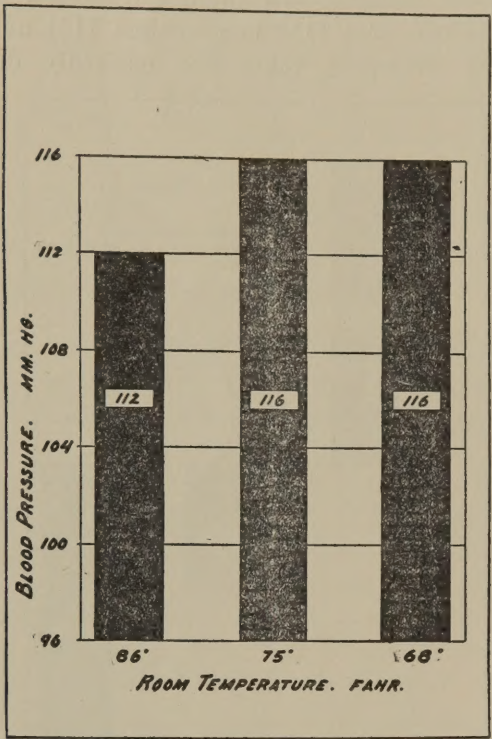

FIG. 4. Relation between Room Temperature and Average Systolic Blood Pressure of all subjects at end of day.

in the total amount of work done in the hot room while with male subjects whose votes as to comfort showed no preference for the 68° over the 75° condition there was as much accomplished in the warm as in the cool room. We plan to repeat these experiments with women subjects who may probably be more susceptible to slight degrees of overheating.

The results with physical work (lifting dumbbells and riding a stationary bicycle) were much more definite. Again maximum effort tests showed no appreciable influence of room temperature, but when the subjects had a choice they accomplished 15 per cent. less work at 75° and 37 per cent. less at 86° than at 68°. These conclusions are quite what one would expect. Under pressure efficient work can usually be accom-

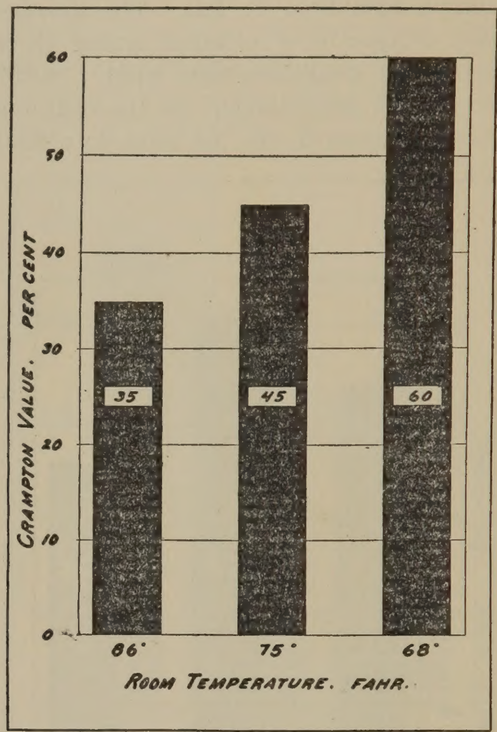

FIG. 5. Relation between Room Temperature and Average Crampton Value for all subjects at end of day.

plished even under unfavorable conditions, but as a matter of common experience we find that the children in overheated schoolrooms and the workers in overheated factories are listless and inactive.

Experiments are now under way in regard to the influence of overheated rooms upon susceptibility to respiratory disease which promise to confirm the observations of Leonard Hill as to the changes in the mucous membranes which follow exposure to hot and dry air, while we find that the resistance of animals to artificial infection is very definitely lowered by chill following exposure to a hot atmosphere.

As to the effect of stagnant breathed air,

contaminated by a group of subjects so as to contain on an average from 20 to 60 parts of carbon dioxide per 10,000, our observations are entirely negative, so far as the physiological and psychological and efficiency tests above mentioned are concerned. So long as the room temperature was the same it seemed to make not the slightest difference to our subjects whether the air in the chamber was stagnant or was renewed at the rate of 45 cubic feet per minute per capita—except in one particular respect to be discussed more fully below.

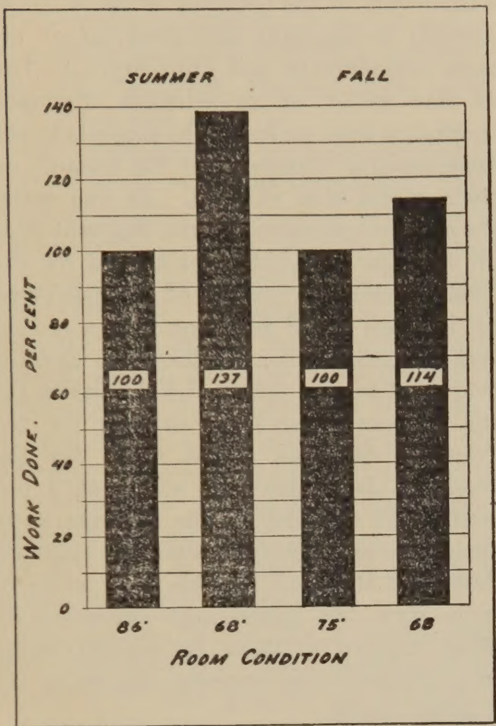

Fig. 6. Relation between Room Temperature and Average Amount of Physical Work accomplished during the day, in summer and fall experiments.

It is perhaps not unnatural that these results, like the similar results of earlier investigators, should be popularly misinterpreted as meaning that ventilation of any kind is a needless luxury. When the first progress report of the commission was discussed in a New York paper under the headline, "Commission put its O. K. on Stagnant Air," the curator of a large college building at once called upon the chief of the investigating staff to ask if he would be justified in stopping his fans. Such a conclusion as this is, of course, quite unjustified and most unfortunate in its effects. No scientific investigations can contradict or minimize the well-established results of experience as to the bad effects of poor ventilation and the beneficial results of fresh air. What physiological research has done is to show why bad air is bad—primarily on account of its high temperature and lack of cooling air movement, sometimes combined with high humidity. In our experimental rooms we can separate the factors of stagnation and overheating, but in practise an unventilated room (if at all crowded) is an overheated room. Ventilation is just as essential to remove the heat produced by human bodies as it was once thought to be to remove the carbon dioxide produced by human lungs.

Even the quantitative standards of air change established on the old chemical basis serve very well on the new physical one. For example, according to Pettenkofer's classical figure, which is a very low one, an adult gives off 400 British thermal units per hour. Let us assume that this heat must be removed by air entering the room at 60° and leaving it not above 70°. One B. T. U. raises the temperature of about 50 cubic feet of air by 1°, or the temperature of 5.0 cubic feet of air from 60° to 70°. Hence our average adult producing 400 B. T. U. will require 2,000 cubic feet of air per hour at 60° to keep the surrounding temperature from rising. An ordinary gas burner produces 300 B. T. U. per candle-power hour; therefore each such burner requires 1,500 cubic feet of air per candle power. These calculations, of

course, ignore direct heat loss through walls and ceiling which with a zero temperature outside may carry off the heat produced by 50 or 100 people. Ventilation provisions must, however, be based on the least, rather than on the most, favorable conditions. In crowded auditoria every bit of the 2,000 cubic feet of air is needed, and in many industrial processes where the heat produced by human beings and illuminants is reinforced by the friction of machinery and the heat from solder pots, furnaces, mangles, pressing irons and a host of other sources, even more will be required.

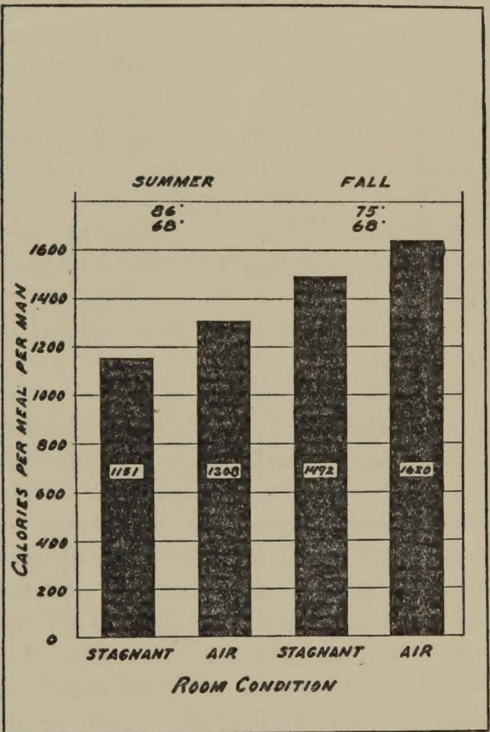

FIG. 7. Average Calorific Value of luncheons eaten with ample supply of fresh air and with no fresh air supply. In both summer and fall experiments the same conditions as to temperature and humidity prevailed through each series.

Furthermore, the recent studies of the New York State Commission suggest that there may, after all, be certain deleterious effects resulting from the chemical composition of the stagnant air of occupied rooms, entirely aside from its temperature. As noted above, all the ordinary physiological and psychological tests failed to show any such effect; but in one particular we noted a difference in the behavior of the subjects exposed to stagnant and fresh air of the same temperature and humidity. In two of our series of experiments standard luncheons were served to the subjects in the experimental chamber and the amount on their plates was weighed. In one series the subjects consumed on the stagnant days an average of 1,151 calories and on the fresh-air days an average of 1,308 calories, an increase of 13 per cent. In a second series during colder weather, the average consumption was larger, 1,492 calories for the stagnant and 1,620 calories for the fresh-air days, an excess again for the fresh-air days, this time of about 9 per cent. The opinions of the subjects as to their comfort slightly favored the stagnant days, but it seems possible that odors of some sort, not consciously perceived by those exposed to them for several hours, may yet affect the appetite and hence the general health.

Even if further investigations should fail to confirm this result, it is my personal feeling that occupied rooms should be kept free from noticeable odors as a measure of public decency if not of public health. The cleanliness which results from the habit of bathing, except for the washing of the hands before eating, has, so far as I am aware, no important sanitary results. Just as the people who have been in a close room do not notice the odors which have accumulated during their occupancy, the person unaccustomed to bathing is unconscious of the effect produced, yet common decency rightly demands both bodily cleanliness and fresh air.

Recent research has, on the whole, strengthened rather than weakened the

arguments for ventilation. It has shown, however, that the physical quality of the air as well as its amount must be considered, and that a room supplied with air at the room inlet which will explode a thermometer registering to 125° (which happened to the instrument of one of my investigators in a New York City school) is not well ventilated, however many cubic feet of air may enter it.

The thermometer is the first essential in estimating the success of ventilation. Temperature standards must come into general use and a rise above 70° must be recognized as a sign that discomfort is being produced and efficiency decreased and vitality lowered. The carbon dioxide standard is still of value, however, as ordinarily a measure of the air change which is required to carry off both heat and odors; and the mechanical standard of thirty cubic feet of air per minute per capita as the amount necessary to supply in some way if an occupied room is to remain cool and fresh is still of general application.

The question of humidity is perhaps the most important one which remains to be solved before the practise of ventilation can be placed on a sure basis. A lack of humidity, as Professor Phelps has pointed out, makes hot air feel cooler and cold air feel warmer. Extreme dryness per se, however, at high or moderate temperatures, is believed by many to be in itself harmful, conducing to nervousness and restlessness and producing injurious effects upon the membranes of the nose and throat. There is, unfortunately, no solid experimental evidence upon this point, and this is one of the most important subjects which the N. Y. State Commission hopes to be able to study during the coming year.

It is a foolish empiricism which maintains that outdoor air as Nature makes it is necessarily the final word in air conditioning. The task of applied science is to find out the best elements in a natural environment and to select the good without the bad.

Only as we succeed by the application of the methods of research in disentangling and measuring the various factors involved in atmospheric influence shall we be able to establish sound standards for the practical art of ventilation.

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